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RESEARCH PAPER

# Assessment of Carbon Balance in Community Forests in Dolakha, Nepal

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**Abstract** This study assessed the net above-ground carbon stock in six community forests in the Dolakha district, Nepal. A survey was conducted of above-ground timber species, using random sampling. A tree-ring chronology for *Pinus roxburghii* was created to construct a growth model representative of the various mainly-pine species. The allometric model combined with tree ring analysis was used to estimate carbon stock and annual growth in the above-ground tree biomass. The out-take of forest biomass for construction material and fuelwood was estimated on the basis of interviews and official records of community forest user groups. The average annual carbon increment of the community forests was 2.19 ton/ha, and the average annual carbon out-take of timber and fuelwood was 0.25 ton/ha. The net average carbon balance of 1.94 ton/ha was equivalent to 117.44 tons of carbon per community forest annually. All the community forests were actively managed leading to a sustainable forest institution, which acts as a carbon sink. It is concluded that community forests have the potential to reduce emissions by avoiding deforestation

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and forest degradation, enhance forest carbon sink and improve livelihoods for local communities.

**Keywords** Above-ground woody biomass · Climate change · Deforestation · *Pinus roxburghii*

## Introduction

Forests can sequester more carbon than any other terrestrial ecosystems (IPCC 2001; Lal 2005; Gibbs et al. 2007). They can store more carbon dioxide ($CO_2$) (4,500 Gt) than the atmosphere (3,000 Gt) (Prentice 2001). However, the carbon stock varies widely among latitudes (Dixon et al. 1994; Lal 2005), about 49 % of terrestrial carbon stock being found in high latitude forests, 14 % in mid-latitude forests and 37 % in low latitude forests (Dixon et al. 1994; Lal 2005). Carbon sequestration is a complementary service of forests and sustainably managed forests are reliable sinks of greenhouse gases (GHGs) (Levy et al. 2004).

Depending on the succession stage or management regime, forests can act as a carbon source or a sink (Masera et al. 2003). When the forest ecosystem is disturbed (cleared, degraded or converted to other land uses), the earlier carbon stored in the above-ground and below-ground biomass and in the soil is released back to the atmosphere in the form of $CO_2$ (Lal 2005; Gibbs et al. 2007). Deforestation and forest degradation are responsible for emitting GHGs (Dixon et al. 1994; Masera et al. 2003; Gibbs et al. 2007). Deforestation and forest degradation directly affect the carbon stored in the above-ground living biomass of trees (Gibbs et al. 2007). On the other hand, restoration of degraded forests and soil has globally a potential for storing carbon in terrestrial ecosystems corresponding to 50–75 % of the historic losses (Lal 1999; Upadhyay et al. 2005).

The united nations framework convention on climate change (UNFCCC) together with the Kyoto Protocol recognized the importance of reducing emissions from deforestation and forest degradation (referred to as REDD) in developing countries through preserving and sequestering carbon in forests (Gibbs et al. 2007; Staddon 2009). The authors take the view that community-based forest management (CBFM) is a successful example of forest management, and is the preferable option of carbon sequestration in developing countries [as argued by Klooster and Masera (2000) and Staddon (2009)]. Nepal, one of the world's least developed countries, is a pioneer in adopting CBFM, and has a well documented history of community forestry (Gautam et al. 2004; Staddon 2009). Nepal's community forestry has become an example of innovative operation, progressive legislation and evolving practices in the decentralization of forest management (Acharya 2002; Gautam 2009; Giri and Ojha 2010). Nepal's community forestry has met with some notable successes in terms of strengthening social capital and improving the ecological condition of the forests (Acharya 2002; Gautam et al. 2004; Gautam 2009).

Nepal's decentralized and participatory forest policies have helped to restore numerous degraded ecosystems (Acharya and Kafle 2009). Nepal is predominantly an agricultural country, where agriculture and forestry contribute 36.56 % of the

total gross domestic product (MOF 2012). More than two-thirds of the national population depend on agriculture for their employment and livelihood, often supplemented by livestock (MOF 2012). Rural communities rely entirely on forests for firewood, fodder, timber and other non-timber forest products (WECS 2010). Thus, in the context of Nepal, community forestry not only sequesters carbon, but also plays a pivotal role in diversifying livelihoods and increasing socio-ecological resilience against climate change (Joshi et al. 2010). Currently, approximately 30 % of national forest land (1.3 M ha) has been handed over to more than 15,353 community forest user groups (CFUGs) involving 1.8 M households (MOF 2012).

Forests managed under the scheme of community forests have frequent removal of forest biomass, and thus monitoring carbon sources and sinks is in general critically important to understanding the processes that affect the net carbon balance (Stinson and Freedman 2001; Mandal and Laake 2007). In particular, biomass volume is an important indicator of forests' potential to sequester carbon (Dixon et al. 1994; Brown 2002; Masera et al. 2003; Lal 2005; Gibbs et al. 2007; Mandal and Laake 2007). The main objective of this paper is to assess the effectiveness of community forest management in conserving and building carbon stock. In this study, allometric equations which calculate the species-wise biomass are used to estimate aggregate carbon in community forests, and changes in above-ground timber biomass (AGTB) are estimated using annual tree rings in combination with allometric equations.

## The Study Area

This study was conducted in Dolakha district, in the Janakpur zone of the Central Development Region of Nepal. Dolakha district was selected because the community forestry program has been implemented there since the early 1980s and the district has CFUGs practicing forest standard certification processes. Additionally, this district has been selected for the REDD pilot study in Nepal. Dolakha is located at 85°50′E to 86°32′E longitude and 27°28′N to 28°00′N latitude, and the altitude varies from 732 m to 7,148 masl (DDC 1999). The district covers about 2,191 km$^2$, of which 35 % is high Himalayan mountains, 40 % high hills and 25 % mid-hills (DDC 2011). The average annual precipitation is 2,043 mm (DDC 2011).

Due to variations in altitude, the relatively small territory of Dolakha district exhibits remarkably diverse climatic conditions (DDC 1999). Forest land occupies 47.37 % of total land area, followed by agriculture (26.45 %) and pasture land (13.77 %) (DDC 2011). The dominant tree species is *Pinus roxburghii* (45 %), and the associated species are *Schima wallichii* (14 %), *Pinus wallichiana* (12 %), *Shorea robusta* (11 %), and others (Rhododendron, *Alnus nepalensis, Quercus, Pinus pitual, Schima castonopsis* 18 %) (DDC 1999).

Six community forests, within the Charnawati catchment of Dolakha district were selected for this research. The Charnawati is a tributary of the Tamakoshi River and has an altitude range of 850–3,500 masl. The total area of this catchment is 14,049 ha, of which 5,996 ha is covered by forests, and there are 58 CFUGs within this catchment (Shrestha 2011). The selected community forests are Simsungure, Mahankal,

Mathani, Sitakunda, Barkhe Dadapari and Chyansi Bhagwati. These community forests were selected because they are mainly pine-dominated forests (three pure pine and three mixed types). All the community forests were handed to the community at least 10 years ago. Accessibility to the researcher was also considered while selecting the community forests, all of which are located around the district headquarter at Charikot. Some of the attributes of the selected community forests are reported in Table 1.

## Research Method

After selection of the forests based on forest type, simple random sampling was carried out to compile a forest inventory. A total of 66 rectangular plots (25 m × 10 m) were used in the six community forests. Ten plots were inventoried randomly in each community forest except Sitakunda community forest (16 plots were sampled due to its larger area) to measure all trees greater than 10 cm in diameter. In all plots, tree diameters were measured at breast height (DBH), of 1.37 m above the ground, and tree heights (H) were measured with a clinometer.

### Biomass and Carbon Estimation

Estimations of AGTB were performed by using the allometric equation developed by Sharma and Pukkala (1990):

$$\ln(\mathrm{V}) = \mathrm{a} + \mathrm{b}\ \ln(\mathrm{DBH}) + \mathrm{c}\ \ln(\mathrm{H})$$

where V = the total stem volume with bark in $m^3$, DBH = diameter at breast height over bark (cm), H = total tree height (m), a, b, c = species-specific constants.

The values for species specific constant, for *P. roxburghii* are, a = −2.9770, b = 1.9235, and c = 1.0019 with coefficient of determination $R^2 = 99.2\ \%$ (Sharma and Pukkala 1990).

The over-bark volume of each tree obtained using the above equation was multiplied by the species-specific wood density to obtain the stem biomass. Estimates of biomass stock dating back to 2006 were calculated by subtracting the diameter and height increment for the last 5 years and applying the same allometric equation. The biomass was then converted into amount of carbon assuming 50 % of dry weight biomass is carbon, following MacDicken (1997).

### Tree Ring Analysis and Estimation of Annual Growth in AGTB

A total of 54 *P. roxburghii* tree cores were collected with a standard increment borer of 0.4 cm diameter to determine the age of the species from tree-ring analysis. Boring was done horizontally at a standard height (1.37 m). Tree stems with advanced decay, deformities, suppressed growth or directional lean were avoided. Tree cores were mounted in wooden frames and sanded with increasingly fine grades of sandpaper. Ages of individual trees were calculated by visual counting of

**Table 1** Some important attributes of the six selected community forests

| CFUG | Simsungure | Mahankal | Mathani | Sitakunda | Barkhe dadapari | Chyansi bhagwati |
|---|---|---|---|---|---|---|
| Area (ha) | 33.35 | 39.38 | 28.28 | 141.31 | 35.4 | 30.32 |
| Estab year[a] | 1994 | 1994 | 1996 | 1994 | 1997 | 1998 |
| No. of HH[b] | 61 | 107 | 67 | 135 | 107 | 93 |
| Altitude[c] | 1,200–1,600 | 1,000–1,500 | 1,750 | 900–1,400 | 1,000–1,500 | 1,400–1,700 |
| Dominant species | *P. roxburghii* | *P. roxburghii* | *P. roxburghii, S. wallichii, Alnus nepalesis* | *Pinus roxburghii* | *P. roxburghii, Rhododendron, S. wallichii* | *P. roxburghii, Alnus nepalensis, Rhododendron, S. wallichii* |

Source: Shrestha (2011)

[a] Year established

[b] Households

[c] Altitude (m above sea level)

the rings, noting down the radius with a precision of 1 mm. Tree diameter was estimated as

$$\mathrm{DBH} = \mathrm{a} + \mathrm{b(age)}$$

Tree height was regressed on diameter to obtain the quadratic equation:

$$\mathrm{H} = \mathrm{a(DBH)}^2 + \mathrm{b(DBH)} + \mathrm{c}$$

The relationships between DBH and age and between DBH and H were used to establish mean diameter and mean height 5 years ago. These parameters together with tree density provided the necessary measure to estimate a proxy for mean biomass of 5 years ago, and subsequently the annual increase in biomass from 2006 to 2011.

### Data Analysis

Collected data were analysed using the software R, Microsoft Excel 2007 and statistical package for social sciences (SPSS 16). The core samples from living *P. roxburghii* trees were analyzed visually, recognizing and noting the signature patterns of dark and light bands of rings. Linear regression analysis was employed in the statistical modeling of the relationship between the age and diameter data using R. Likewise, regression was performed for diameter and height data. One-way analysis of variance (ANOVA) and *t* testing were performed to check significance levels.

## Results

The density of major canopy timber trees ($\geq$10 cm DBH) varied between 416 and 644 stems per hectare (sph) across CFUGs (Table 2). Mean DBH was between 18 and 22 cm. Basal area varied between 13.42 $m^2$/ha in Barkhe to 27 $m^2$/ha in

**Table 2** Stand parameters of major canopy timber trees with DBH over 10 cm

| Parameter | Unit | Community forest user group | | | | | |
|---|---|---|---|---|---|---|---|
| | | Simsungure | Mahankal | Mathani | Sitakunda | Barkhe | Chyansi |
| Tree density | Tree/ha | 556 | 496 | 600 | 458 | 416 | 644 |
| Mean DBH (±) | cm | 21.74 ± 12 | 18.77 ± 9 | 19.26 ± 6 | 21.03 ± 11 | 18.1 ± 9 | 18 ± 5.95 |
| Range of DBH | cm | 10–64.5 | 10.1–59 | 10.1–41 | 10.1–52 | 10.1–53 | 10–36.5 |
| Mean H (±) | m | 12.94 ± 4.4 | 12.1 ± 4.71 | 12.06 ± 3 | 13.08 ± 5 | 10.67 ± 5 | 12.04 ± 4 |
| Range of H | m | 2.78–26.85 | 4.5–30.05 | 4.5–22 | 2–27 | 4–27.5 | 2.3–25 |
| Basal area | $m^2$/ha | 27 | 16.73 | 19.37 | 20.54 | 13.42 | 18.17 |

The ± sign shows the standard error in no particular direction (right and left of the mean value)

Simsungure. Size class distribution was relatively well behaved, with higher DBH classes having smaller numbers of trees, as is typical of natural forests with active regeneration and recruitment. The presence of abundant younger trees is an indication that there is potential to enhance forest carbon-stock. This ensures sustainability of carbon stock and sequestration for carbon trading in future.

Empirical relationships of age versus DBH and height versus DBH of *P. roxburghii* showed a positive linear relationship. Linear regression analysis of age and DBH produced a slope coefficient of 0.6427, indicating that each year increase in age increases the diameter of the species on average by 0.6427 cm. The coefficient was significant at the 1 % level ($df = 1, 51$). The $R^2$ value indicates that age explains 69 % of the variance in diameter. Height increases with the increase of DBH steeply at first and then almost levels off. The relationship obtained between DBH and height was also significant at the 1 % level, with a coefficient of determination 0.77 ($df = 2,365$).

### Current Forest Biomass, Annual Growth and Annual Extraction of Forest Products

The current forest biomass of the six community forests vary from about 1,400 tons (Barkhe) to over 13,300 tons (Sitakunda) (Table 3). On average, the community forests have about 4,000 tons of timber biomass which is equivalent to 70.8 tons/ha. The pine-dominated forests have more biomass than mixed forest. The Welch two-sample $t$ test on differences between biomass of mixed and pine forests gave a $p$ value of 0.03469, indicating that biomass varied between forest types.

The annual biomass increment varied from 1.53 ton/ha/year in Barkhe to 6.11 ton/ha/year in Sitakunda (Table 4). The quantity of sawlog timber extracted was greater than that of firewood.

### Carbon Balance of the Community Forests

As depicted in Table 5, all community forests are sequestering a substantial amount of carbon. On average, the community forests accumulate approximately 2 ton/ha of carbon annually which is equivalent to 117.44 tons of carbon in total. The $t$ test revealed a significant difference between carbon increment and out-take ($p < 0.01$).

**Table 3** Forest biomass in the study area, 2011

| Community forest | Total biomass (ton) | Biomass (ton/ha) | Forest type |
|---|---|---|---|
| Simsungure | 3,110.26 | 93.26 | Pine |
| Mahankal | 2,908.56 | 73.86 | Pine |
| Mathani | 1,906.97 | 67.43 | Mixed |
| Sitakunda | 13,328.2 | 94.39 | Pine |
| Barkhe Dadapari | 1,427.79 | 40.33 | Mixed |
| Chyansi Bhagwati | 1,683.16 | 55.51 | Mixed |
| Average | 4,060.82 | 70.8 | |

**Table 4** Annual biomass growth and extraction in the studied CFUGs

| Community forest | Annual biomass growth (ton/ha/year) | Annual biomass extraction (ton/ha/year) | |
|---|---|---|---|
| | | Timber | Firewood |
| Simsungure | 5.79 | 0.28 | 0.064 |
| Mahankal | 5.19 | 0.62 | 0.14 |
| Mathani | 3.51 | 0.77 | 0.18 |
| Sitakunda | 6.11 | 0.22 | 0.078 |
| Barkhe | 1.53 | 0.25 | 0.06 |
| Chyansi | 4.06 | 0.20 | 0.12 |

**Table 5** Annual carbon balance of the community forests

| Community forest | Carbon sequestration (ton/ha/year) | Carbon out-take (ton/ha/year) | Carbon balance (ton/ha/year) | Total Carbon storage in forest (ton/year) |
|---|---|---|---|---|
| Simsungure | 2.9 | 0.17 | 2.73 | 91.04 |
| Mahankal | 2.6 | 0.38 | 2.22 | 87.42 |
| Mathani | 1.76 | 0.47 | 1.29 | 36.41 |
| Sitakunda | 3.06 | 0.15 | 2.91 | 411.32 |
| Barkhe | 0.77 | 0.15 | 0.62 | 21.83 |
| Chyansi | 2.03 | 0.16 | 1.87 | 56.6 |
| Mean | 2.19 | 0.25 | 1.94 | 117.44 |

The average standing living timber biomass of the selected six community forests for 2011 was estimated to be 70.8 ton/ha. This is slightly lower than the estimate by Baral et al. (2009) of 86.02 ton/ha in chirpine (*Pinus roxburghii*) forest in Lalitpur district, Nepal. In another study, Adhikari (2011) estimated the average AGTB in the chirpine forests of Salyan of about 145.71 ton/ha. The lower biomass and carbon estimates in the current study were due to the exclusion of low-diameter trees in the community forests. Many poles—with DBH less than 10 cm—were observed; these indicate high potential for increased $CO_2$ uptake in the coming years. Forest biomass comparison between present and past (5 years earlier) showed considerable increase in the AGTB. Banskota et al. (2007) estimated 1.88 ton/ha/year in the community forests of Nepal under normal management conditions. Since the management of community forests is highly similar to that in Nepal, various natural factors including vegetation type and age of the stand, and locality factors such as soil fertility and climate, might have influenced the carbon sequestration rate estimates.

## Discussion and Conclusions

The six studied community forests are functioning as effective carbon sinks. It can be concluded that the forests under community management offer great potential to

deliver carbon stock increases. Because the carbon gains due to forest enhancement cannot be claimed under the clean development mechanism, which allows only for afforestation and reforestation, the sites investigated will be eligible in principle under REDD. This signifies the importance of community forest management for sustainable management of forests as a valid means of achieving REDD goals. Thus, it is imperative that community forest management can be considered as part of the government's approach under the REDD policy.

CFUGs play an important role in total carbon sequestration in Nepal, where about one third of the forests are under community management. While negotiations on a wider climate change agreement continue, Nepal is forging ahead with its preparations to implement REDD+. REDD+ offers a wider range of mitigation opportunities than REDD alone (Adhikari 2011). Most significantly, REDD+ goes further than just rewarding actions that reduce emissions, and will also reward practices that create new carbon sinks or conserve and enhance existing sinks that result from sustainable management practices (Karky and Skutsch 2010). Hence REDD+ is of particular relevance to Nepalese community forests. Once REDD+ comes to function in Nepal, large sections of CFUGs will have the opportunity to share benefits from carbon trading.

Although the management of community forest was not designed for the purpose of carbon sequestration, it is clear that there is enormous potential for increasing sequestration using relatively simple forest management practices. It is imperative that carbon sequestration be included in the operational plans of CFUGs. Concern has been expressed that REDD policies focused on preserving carbon might lead to the preservation of carbon-rich forests at the expense of other environmentally valuable forests and ecosystems, leading to depletion of overall biodiversity (Joshi et al. 2010; Karky and Skutsch 2010). However, this study reveals that approximately 2 tons of carbon/ha/year is sequestered under normal management conditions, that is, after local users extract timber to meet their subsistence needs. Assuming a price of US $5[1] per ton of carbon net of transaction costs, revenue of $10/ha would be generated if carbon could be traded. Though not a large amount, this is additional revenue that the CFUGs can deploy for community benefit. Hence the pro-poor focused policy of community forests can provide a sustainable livelihood for many marginalized people. More importantly, CFUGs can become a strong safety net for the poor and local communities in coping with, and adapting to, climate change impacts. In other words, sustainable forest management by forest-users is both a mitigation and an adaptation strategy.

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[1] 1 US$ = 83.44 NRP as of October 15, 2012.

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